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Temporal Intervals Production During Passive Self-Motion in Darkness

Aurore Capelli, Renaud Deborne and Isabelle Israël

1 Numerous studies suggested that motion reproduction without vision (during vestibular and somatosensory stimulation) could rely on time processing. Likewise, a number of projects investigated time estimation responses during additional sensory stimulation (Treisman, Faulkner, Naish, & Brogan, 1990; Burle & Bonnet, 1997; Burle & Casini, 2001). However, little attention is devoted to the interactions between self-motion and time processing. This paper examines the influence of self-motion and particularly of vestibular (and somatosensory) stimulations on human timing capacities.

2 Self-motion is the motion of the whole body (with the head), that can be measured mainly by the vestibular system. The detection of linear acceleration is due to the otoliths (Young, 1984), while the semi circular canals respond to angular acceleration (Guedry, 1974).

3 The vestibular contribution to distance estimation and to path integration in darkness has been studied in various researches (Georges-François, Grasso, Berthoz, & Israël, 1995; Loomis, Klatzky, & Golledge, 2001; Mittelstaedt & Mittelstaedt, 2001). The main results demonstrated an overestimation of the travelled distance in darkness. Israël et al. (2004) found that while vestibular information was insufficient to accurately estimate the traveled distance, time estimates were used. Furthermore, when the participants were asked to reproduce the previously traveled distance, the duration of their response was as accurate as the distance (Berthoz, Israël, Georges-François, Grasso, & Tsuzuku, 1995). Recently, Glasauer, Schneider, Grasso and Ivanenko (2007) used a dual-task paradigm during reproduction of travelled distance tasks and showed that both motion distance and duration reproductions were impaired with cognitive load. Thus, self-motion and temporal processing seem interdependent.

4 Several studies underlined that time and space processing seem interrelated. Lappe, Awater and Krekelberg (2000).reported a compression of space at time of saccades. The apparent position of objects briefly flashed is perceived shifted at the position of the

saccadic target. Morrone, Ross and Burr (2005) describe a similar compression phenomenon but for time. When the temporal interval between two pairs of bars were presented just before the saccadic onset, shorter and more precise temporal interval estimations were found than longer before or after the onset. The authors suggested that those distortions may rely on a common neural mechanism. Furthermore, Walsh (2003) proposed A Theory Of Magnitude (ATOM) that posits that time, space and quantity are part of a generalized system.

5 How is time processed? Several authors suggested that there are at least two types of timing processing (Fraisse, 1963; Lewis & Miall, 2003; Mauk & Buonomano, 2004; Rammsayer & Lima, 1991). Timing in the duration range of milliseconds to one second is an automatic process mainly associated with motor behaviour (i.e. production of skilled movements such as finger tapping). On the other hand, the timing mechanism of intervals in the range of seconds stands for duration discrimination and implies cognitive processes.

6 Several models focused on timing of motor behaviour. The behavioural theory of timing (BeT) (Killeen & Fetterman, 1988) is an alternative to the cognitive model of scalar expectancy theory (SET) (Gibbon, 1977; Gibbon & Church, 1990). According to the BeT, pulses from an internal pacemaker generate transitions between states correlated with "adjunctive" behaviours, coming to serve as conditional discriminative stimuli for temporal processing. The pulses rate of the pacemaker was shown to be proportional to the frequency of reinforcement. More recently, Ivry (1996) and Ivry & Richardson (2002) proposed the Multiple Timer Model to account for the timing of short-range duration. This model assumes the existence of a time system constituted of a set of hourglasses that would be duration- and task-specific, and of a central gating process that provides the link between the time system and the motor execution. Those two models posit that automatic timing is based on timer(s) tuned to represent particular intervals.

7 According to Ivry & Richardson (2002) and Ivry & Spencer (2004), the time system responsible for the representation of intervals of short-time range is located in the cerebellum. Indeed, patients with cerebellar damage showed impairments during accurate timing required for production task (finger tapping), perceptual duration judgement task and eyeblink conditioning (Ivry & Keele, 1989; Mangels, Ivry & Shimizu, 1998; Nichelli, Alway, & Grafman, 1996; Perrett, Ruiz, Mauk, 1993). Recently, Gerwig et al. (2003, 2005) showed that the timing of conditioned eyeblink responses was impaired for patients with cortical cerebellar degeneration and lesions of the superior cerebellum but not for patients with lesions restricted to the posterior and inferior cerebellum.

8 Interestingly, the cerebellum receives vestibular and proprioceptive information (Barmack, 2003). Since the cerebellum is involved in both vestibular processing and timing functions, we posit that self-motion stimulating the vestibular system could lead to special timing processing perturbations.

9 Only few results are known about time estimation under vestibular modality. Frankenhaeuser (1960) showed that subjects seated at the end of a rotating arm (3g centrifugal acceleration) reproduced temporal intervals systematically shorter than when stationary.

10 Semjen, Leone and Lipshits (1998A) observed a decrease in the accuracy and regularity of timing under microgravity, where the otolith signal reference is missing. Using the Wing and Kristofferson (1973) decomposition of variance analysis, they found an increase of the

central timer variance (and not of the motor execution variance) under microgravity. Semjen, Leone and Lipshits (1998) proposed that perturbations of the central timer under microgravity are due to reduced vestibular and proprioceptive afferent signals to the cerebellum.

11 These two results suggest an influence of the vestibular stimulation on timing.

12 In the present study, a temporal interval production task was used, requiring to push a button each second. We examined whether passive self-motion in darkness, stimulating the vestibular (and somatosensory) system, could perturb time estimation accuracy, regularity or evolution, compared to immobility. We expected that varying velocity profiles would produce an effect due to the vestibular stimulation exerted on the internal timekeeper.

13 Ten healthy right-handed volunteers (4 men and 6 women, aged 22 to 36 years) participated in the experiment, after giving informed consent to the protocol compliant with the local institutional ethical committee.

14 The participants were blindfolded and wore headphones delivering white noise. They were seated on a mobile robot (Robuter: Robosoft, France) controlled by a PC micro-computer (see Berthoz et al. 1995), which can rotate about the earth-vertical axis and can move linearly. The participants were required to push a button held in their right hand. The button presses and the position of the robot (detected via optical odometry) were sampled throughout the experiment at 100 Hz. The maximal linear velocity of the robot is 1m/s and its maximal angular velocity 60°/s. The corresponding maximal accelerations are $1m/s^2$ and $60°/s^2$.

15 The participants were instructed to press the button once each second. The task was performed without training and no feedback was available to the participants about their performances.Furthermore, no instruction was given about the strategy to correctly estimate the temporal intervals of one second

16 Each trial contained two phases: one phase without motion (No Motion Phase, lasting about 15 s), followed by a phase with self-motion (Motion Phase). The participants were requested to press the button without pausing throughout the two phases. The motion phase was always performed after the no motion phase, as in Israël et al. (2004) the motion trials had no influence on the no motion trials performance.

17 Passive displacements were used in order to limit possible influences of motor signals. Indeed, Mittelstaedt and Glasauer (1991) found that distances were differently estimated during walking compared to passive transport.

18 Motion stimuli were leftward rotations or forward translations (cf. table 1), simulating respectively the semi-circular canals or the otoliths.

19 Since the vestibular system detects acceleration but not constant velocity, displacements with various velocity profiles were used. Motion phases with constant velocity and with varying velocity profiles were applied.

20 With constant velocity, the initial and final acceleration pulses were $1m/s^2$ or $60°/s^2$ and velocities were 0.6m/s or 35°/s (cf. figure 1). The motion phase lasted about 25 seconds, and the subjects were supposed to press the button at least 20 times.

21 With varying velocity, upward and downward velocity ramps (respectively positive and negative acceleration) were used. In downward velocity ramps, the initial acceleration pulse was high ($1m/s^2$ or $60°/s^2$) and brief (approximately 1 s), up to 1m/s or 60°/s, while

the subsequent deceleration step was minimal (0.08m/s^2 or 4.60°/s^2) and prolonged (15 s) (cf. figure 1). On the contrary, in upward velocity ramps, the initial acceleration step was low (0.08m/s^2 or 4.60°/s^2) and prolonged (15 s) with the same peak velocity as in the downward ramps, and the final deceleration was high (1m/s^2 or 60°/s^2) and short (approximately 1 s). The motion phases lasted about 15 seconds, so that the subjects pressed the button at least 10 times.

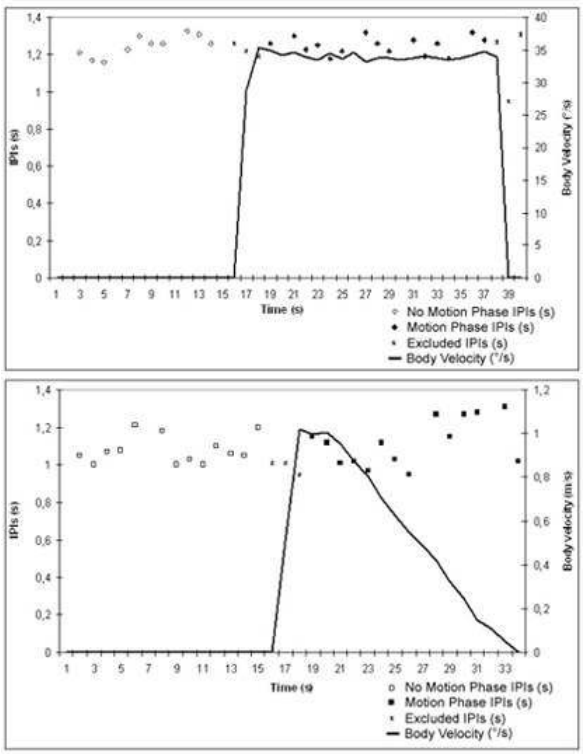
22 The imposed motion parameters (both velocity and acceleration) were higher than the vestibular detection threshold.

23 In the figures, the No Motion Phases and the Motion Phases are distinguished by different colors (white for the No motion Phases and black for the Motion Phases). The trials are indicated with abbreviations: it begins with “R” for rotations, and with "T" for translations; then the second letter indicates the velocity used during the motion phases: “C” for constant velocity , “D” for down velocity and “U” for up velocity.

24 Table 1

25 Motion Phase characteristics (velocity, distance and duration) as a function of all trials (constant, up and down), separately for rotations and translations.

ROTATIONS			
	Velocity (°/s)	Distance (°)	Duration (s
Constant (RC)	35	750	22
Up (RU)	0-60	480	14
Down (RD)	60-0	480	14
TRANSLATIONS			
	Velocity (m/s)	Distance (m)	Duration (s)
Constant (TC)	0.6	15	24
Up (LU)	0-1	10	16
Down (LD)	1-0	10	16



26 **Figure 1**. *Up figure*: sample recording obtained during RC for participant 6. Inter-Push Intervals (IPIs) in s and rotation velocity (in °/s) over time (in s).

27 *Low figure*: sample recording obtained during TD for the same participant. Inter-Push Intervals (IPIs) in s and translation velocity (in m/s) over time (in s).

28 Rotation and translation stimuli were presented in two separate blocks whose order was systematically varied among the participants. The 3 trials inside each block (constant, upward and downward velocity) were in random order. Each block was repeated three times. The whole experiment thus included 18 trials and lasted about one hour.

29 The experiments took place in the 50 m long corridor of the LPPA at the Collège de France (Paris).

30 No criterion of exclusion of the participants on the basis of their performance was applied. All button presses recorded during No Motion phases were analyzed.

31 During Motion phases with constant velocity only the presses executed during true constant velocity were taken into account, so the first and last three presses, corresponding to respectively initial and final acceleration were excluded.

32 Similarly in the varying velocity trials, during Motion Phases, only the presses recorded during acceleration (Up trials) or deceleration (Down trials) were considered, so either the last three presses were not included (Up trials: the robot decelerates at the end of the trial motion) or the first three presses (Down trials: the robot accelerates at the beginning of trial motion).

33 The accuracy of the inter-press intervals (IPIs) was examined by computing their mean. The regularity of button presses was evaluated on the basis of the IPIs coefficient of variability (standard deviation divided by the mean). In order to analyze the evolution of subjects' press rate along the trial, the slope of the linear regression between the IPIs (Y) and press number (X) was computed, through the "robust fitting of linear models"

computed with the R software. We applied this robust fitting because it is less sensitive to outliers than the ordinary least squares regression. This analysisuses an iteratively reweighted least squares algorithm, with the weights at each iteration calculated by applying the bisquare function to the residuals from the previous iteration.

34 Finally, the Collier and Ogden analysis (2004) was applied (cf. figure 4) to determine the source of the data variability. The Wing and Kristofferson analysis (1973) is usually used to analyse the variability of timing of repetitive discrete motor responses, but in the presence of a drift in the tempo, the Collier and Ogden analysis is preferred. These authors extended the Wing and Kristofferson model and subdivided the variance into three components: clock, motor and drift variance. The clock and motor variance estimates are close to that proposed by Wing and Kristofferson:

35 Clock variance is estimated by

$$\hat{\sigma}_c^2 = 3S_2 - 2S_1$$

36 and the motor variance is

$$\hat{\sigma}_M^2 = S_1 - S_2$$

37 where S1 and S2 are given by

$$S_1 = \frac{1}{2(n-1)} \sum_{i=2}^{n} (Y_i - Y_{i-1})^2$$

$$S_2 = \frac{1}{2(n-2)} \sum_{i=3}^{n} (Y_i - Y_{i-2})^2$$

38

39 Yi stands for the intertap interval.

40 The drift variance can then be estimated by subtracting the clock and motor variance estimates from the total sample variance

$$\hat{\sigma}_D^2 = s^2 - S_1\left(\frac{2}{n}\right) - S_2\left(\frac{n-2}{n}\right)$$

41 Variance estimates can be negative. The common strategy is to set negative variance estimates to zero (Collier and Ogden, 2001, 2004). This strategy was applied on our data.

42 The Shapiro-Wilks test was used to assess the normality of the data. The distributions were found to be normal, allowing to perform Repeated measures ANOVA. The results were considered as statistically significant at $p < 0.05$.

43 In the No Motion phases the participants pressed the button about 13 times, and in the Motion phases the button was pressed 19 times with constant velocity and 12 times both with down and up velocities.

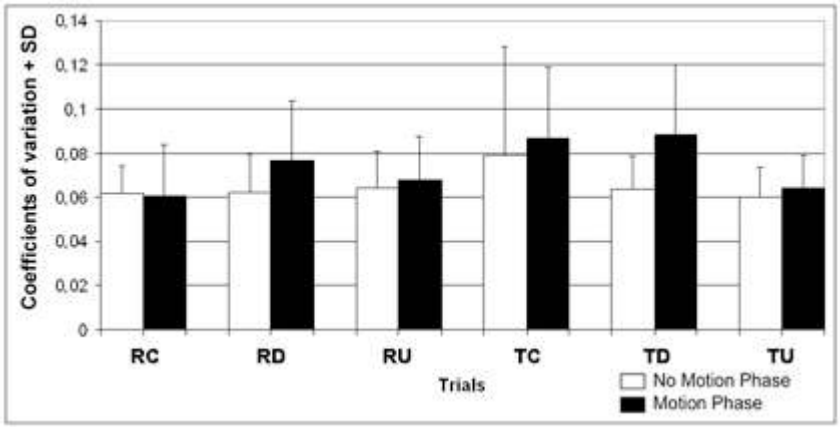
44 As each trial was repeated three times, we checked that there was no effect of the repetition on the performance. In 3 separate ANOVAs called decomposition of variance, the dependent variables were mean IPIs, coefficient of variation of the mean (SD/M) and slope. For all 3 ANOVAs, the random factor was the subjects and the fixed factor was the replication number. No significant effect of the replications was found (all $F(2,18)<2.33$ and all ps> 0.12). This allowed to pool the 3 repeated trials data obtained between replications.

45 We then performed repeated measures ANOVA with 3 within factors (type of motion (Type): rotation, translation; the type of velocity (Velocity): constant, up, down; the presence of self-motion (Phase): no motion phase, motion phase) to determine whether

some of these factors perturbed the temporal productions accuracy, regularity or pushing rate evolution.

46 The mean inter-press intervals (IPIs) of all the trials was first examined. The ANOVA revealed no main effect of the Phase, Type or Velocity on mean IPIs, but a significant Velocity X Phase interaction: $F(2,18) = 6.43$, $p=0.008$. With motion the mean IPIs were shorter than without, for up and constant velocities but not systematically for down velocity. For up and constant velocity, the mean IPIs without motion were respectively 1.31 (± 0.08 s) (mean (± SD), n=10) and 1.26 (± 0.045 s) whereas with motion it was 1.26 (± 0.08 s), and 1.23 (± 0.08 s). For down velocity, the mean of IPIs was 1.25 (± 0.1 s) without motion and 1.25 s (± 0.08 s) with.

47 The variability of the IPIs, reflected by the coefficient of variation of mean IPIs was assessed.



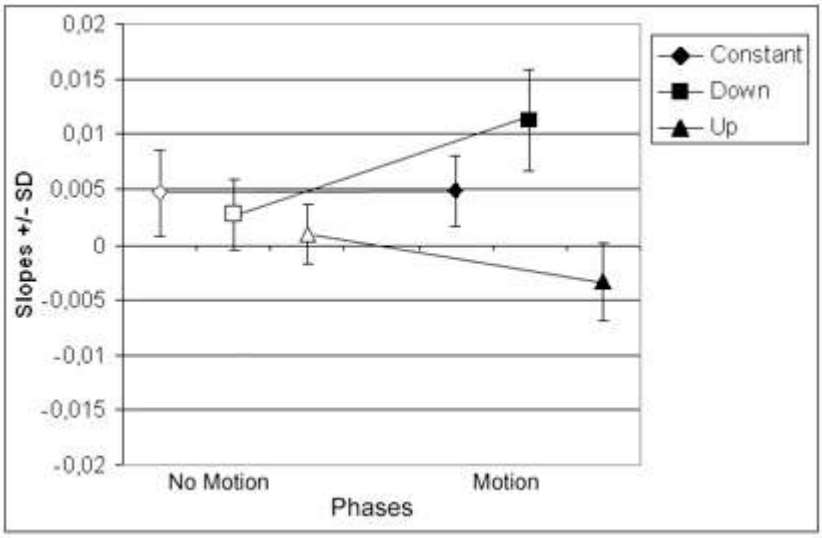
48 **Figure 2.** Coefficient of variation (in s), averaged over all the subjects and replications, as a function of all trials, separately for the No Motion and Motion Phases.

49 We performed the same ANOVA on the IPIs coefficients of variation and found that they were significantly lower for the phases with no motion than with motion ($F(1,9)= 5.23$, $p =0.048$). During the No Motion Phase the mean IPIs coefficient of variation was 0.065 (± 0.021 s) and during the Motion phase it was 0.074 (± 0.025 s). An interaction between Type X Velocity (for both phases) was also revealed ($F(2,18)=4.71$; $p= 0.023$). Coefficients of variation were higher for translations (TD and TC) than for rotations (RD and RC) in trials with down and constant velocity but not with up velocity (cf. figure 2).

50 In order to analyze the evolution of subjects' press rate along the trial, the slopes of the robust regression between the IPIs (Y) and press number (X) over the course of each trial were computed (cf. figure 3).

51 Table 2: Mean slopes, intercepts, correlation coefficients (r^2) and residual standard errors on the degrees of freedom of the robust fitting of linear models between the pressing number and the corresponding IPI as function of all trials, separately for No Motion and Motion Phases.

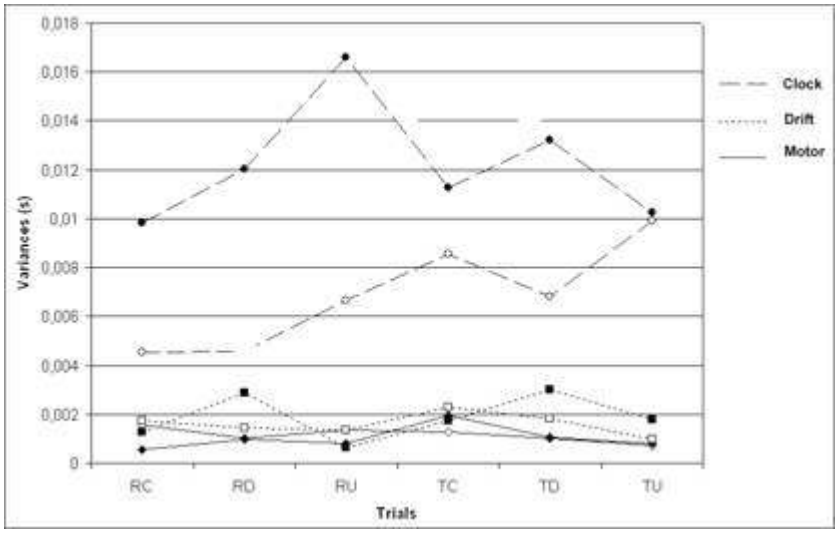
	Slopes				Intercepts				r2		Residual standard errors	
	No Motion Phases		Motion Phases		No Motion Phases		Motion Phases		No Motion Phases	Motion Phases	No Motion Phases	Motion Phases
RC	0,0003	(NS)	0,0002	(NS)	1,22	(<0.01)	1,16	(<0.01)	0,004	0,038	0,092 /37	0,094 /37
RD	0,0003	(NS)	0,0098	(NS)	1,23	(<0.01)	1,21	(<0.01)	0,048	0,121	0,134 /37	0,125 /25
RU	0,0003	(NS)	-0,0117	(NS)	1,23	(<0.01)	1,24	(<0.01)	0,006	0,033	0,103 /32	0,102 /31
TC	0,0004	(NS)	0,0001	(NS)	1,29	(<0.01)	1,24	(<0.01)	0,007	0,008	0,093 /37	0,097 /40
TD	0,0002	(NS)	0,0023	(NS)	1,27	(<0.01)	1,21	(<0.01)	0,045	0,056	0,195 /32	0,129 /28
TU	0,0002	(NS)	-0,0053	(NS)	1,29	(<0.01)	1,26	(<0.01)	0,031	0,068	0,109 /36	0,111 /25



52 Figure 3. Mean slopes ± S.D. of the regression lines between the pressing number and the corresponding IPI against Phase (No Motion and Motion), separately for Up, Down and Constant velocities.

53 The Velocity significantly influenced the slopes (i.e., the pressing rate evolution), $F(2, 18) = 5.06$; $p= 0.018$. With the Tukey post-hoc test it was found that for up velocity trials, the slopes were weaker than for down and constant velocity trials, and were mainly negative (-0.004 ± 0.006). The slopes for down and constant velocity trials were mainly positive and steeper (respectively +0.003 ± 0.008 and +0.0003 ± 0.005). The ANOVA also revealed a significant Velocity X Phase interaction ($F(2, 18) =5.18$; $p= 0.017$) (cf. figure 3). Whereas the slopes were similar with constant velocity during No Motion and Motion phases, the slopes in the varying velocity trials changed between no motion and motion phases. For up and down velocity, the slopes were respectively: 0.0002 (± 0.006), and +0.0002 (± 0.009) during No Motion Phase, and during Motion Phase they were -0.009 (± 0.007) and +0.006 (± 0.009). For constant velocity, the slopes were 0.0002 (± 0.004) with and 0.0003 (± 0.006) without motion.

54 Collier and Ogden (2001) proposed a test statistic (Q), to determine the presence of a drift in the data. Applying this test evidenced the presence of a drift in our data, and thus we performed the analysis proposed by Collier and Ogden (2004) rather than the Wing and Kristofferson's one (1973). The variance estimates of the clock, drift and motor execution were computed (cf. figure 4)



55 Figure 4. Clock, drift and motor variances for all trials, separately for the No Motion Phases (in white) and the Motion Phases (in black).

56 We performed the same repeated measures ANOVA with 3 within factors (Type, Velocity and Phase) on each source of variance. No significant effect was found (all $F(2,18)<4.15$ and all $ps> 0.07$), however the timer variance estimates were systematically higher in the phases with motion than without motion (cf. figure 4). The mean clock variance was 0.0068 (± 0.0062) without motion and 0.0122 (± 0.0137) with motion, whereas the motor variance was 0.0012 (± 0.0014) without motion and 0.0010 (± 0.0010) with motion, and finally the drift variance was 0.0016 (± 0.0018) without motion and 0.0019 (± 0.0022) with motion.

57 We then averaged the variances of each participant across replications and trials. The variance estimates were 0.0095 (± 0.0100) for the clock, 0.0011 (± 0.0012) for the motor implication, and 0.0018 (± 0.0020) for the drift. Thus the graduation between the different variances is similar to that of the usual results (Collier and Ogden, 2001; 2004).

58 The primary focus of this study was to examine whether self-motion in darkness has an effect on subjective timing capacities. The estimation of one second was investigated through button presses while the blindfolded participants were passively moved linearly or angularly at constant or varying velocities.

59 The durations produced by the subjects always exceeded the target interval, which is opposite to what is usually found with the production method (Hornstein & Rotter, 1969). Perhaps the response tool used, requiring the participants to push the button and then to release it rather than just touching the device used in tapping tasks (Vanneste, Pouthas, & Wearden, 2001), decreased the responses rhythm. However, the unexpected temporal overshoot could also be attributed to mental counting. As counting was not forbidden, participants may have used it. The overshoot of the second may thus be due to the additional delay of verbal or mental count preceding the press. As our question was about the effect of self-motion on subjective time, this general bias should not jeopardize the results.

60 The first finding was a change in timing accuracy (mean IPIs) during self-motion. Indeed, the mean IPIs were shorter with motion than without, for up and constant velocity. The results also showed that the variability of the button presses was affected during self-motion as the coefficients of variation were greater with motion than without.

61 We expected changes in timing during varying velocity trials only, but it was not the case. Indeed, during Down velocity ramps (negative acceleration), the accuracy of the pressing rate was not impaired, and moreover constant velocity motion had an influence on timing accuracy and regularity.

62 The fact that constant velocity motion also influenced timing capacities could be partly explained by the vestibular aftereffects (of motion). During rotations after an acceleration pulse, the aftereffects due to canal dynamics decay with a time-constant of approximately 15-20s (Cohen, Henn, Raphan, & Dennett, 1981). In our experiment, the aftereffects during the first 15-20s of rotations may thus have influenced the temporal intervals production.

63 Another explanation is cognitive: Wertheim, Mesland and Bles (2001) submitted their participants to linear self-motion in darkness. When the participants ignored the kind of motion they would experience, they perceived tilts (a well-known vestibular effect), but when they knew it this illusion was (cognitively) suppressed. In the present experiment also, the subjects knew that they were moving because a) they felt the initial acceleration, and b) a motion phase always succeeded a no-motion phase. This knowledge of the planned motion may have cognitively influenced timing mechanism in a similar way as real motion.

64 Finally, the increased response rate (shorter productions) during motion could partly explain the shorter responses in distance estimation found in Israël et al. (1993, 2004).

65 Moreover, an acceleration effect on the tapping rate evolution was evidenced, since in constant velocity the rate was similar during No Motion and Motion phases but it changed between both phases in the varying velocity trials. The participants decelerated their pressing rate during self-motion deceleration, and accelerated their rate during self-motion acceleration. The slopes magnitude can partly explain the stronger variability obtained during self-motion.

66 The results reported in this study support that vestibular and somatosensory stimulation disturbs temporal production (accuracy, regularity and rate). But what is the role of the vestibular stimulation on temporal processing? Several suggestions are here reviewed.

67 In the present study, timing was explored through a production task involving a motor response (of the thumb). The problem is to dissociate the vestibular effect on motor behaviour from that on timing per se. Indeed, the vestibular stimulation may have modified timing processing or may have increased the speed of movement (button push) or both. The Collier and Ogden analysis (2004) was applied to resolve this problem. We expected that vestibular-somatosensory stimulation would modify timing processing only, but it was not the case. Indeed, with vestibular stimulation the timer variance was systematically higher than without, but not significantly. Motor and drift variance estimates did not increase during motion. Based on the systematic and exclusive increase of the timer variance with motion, the greater variability was mainly attributed to the internal timekeeping.

68 Another possibility is that vestibular stimulation increased the activation level devoted to time (arousal). Indeed, Treisman et al. (1990) demonstrated that when adding trains of sensory stimuli, the intervals appeared to last longer and time productions were shorter. Their explanation was that the additional sensory stimulation increased arousal which would consequently increase the output pacemaker frequency. Various replications of this experiment confirmed the main findings (Burle & Bonnet, 1997; Burle & Casini, 2001;

Droit-Volet & Wearden, 2002; Penton-Voak, Edwards, Percival, & Wearden, 1996). Adding a vestibular stimulus could also have shortened the produced intervals. Fetterman and Killeen (1991) showed that the changes in the amount and in the probability of reinforcement affected the temporal discrimination accuracy. They proposed to attribute those perturbations to changes in the pacemaker rate.

69 It is also possible that in our experiment, self-motion distracted participants' attention from time processing. Macar, Grondin and Casini (1994) and Casini and Macar (1997) reported that dividing attentional resources with dual task generates time distortions: a shortening of perceived time (that results in longer temporal productions) and/or an increased variability in timing. Although our experiment was not designed to generate a dual task, it is possible that self-motion in darkness distracted attention from time processing. However, since in the present experiment, self-motion led to shorter temporal productions than no motion, our results are contrary to the classical ones with dual task. On the other hand, the increased variability observed during self-motion is not contrary to the divided attention hypothesis. Indeed, it is plausible that the various velocity profiles distracted the participants from the temporal task. However, as the slopes can partly explain this increased variability during self-motion, it seems difficult to explain why attention should increase the pressing rate during acceleration and decrease it during deceleration but remain constant during constant velocity. For this reason, we do not entirely agree that attention played a critical role in the timing perturbation under vestibular stimulation.

70 Do memory or cognitive processes intervene in our one second interval production task? Rammsayer and Lima (1991) questioned the critical interval of 2 sec proposed by Fraisse (1984) and showed that duration discrimination of 1 sec filled auditory intervals was cognitively mediated, since the performance was impaired by increasing the cognitive load. Moreover, one second is perhaps the duration the most learned during lifespan which means that the estimation of one sec could imply a memory component. However, it has been proposed in the Multiple Timer Model (Ivry & Richardson, 2002) that short durations (such as one second) could be tuned by some nervous network in the cerebellum.

71 The present study attempted to contribute to the idea of motion and time interdependence, and showed that temporal production is shortened and more variable under vestibular stimulation.

72 The finding that time perception may depend on vestibular processing could have severe consequences for vehicular travel in which time estimation is relevant information or for space exploration activities under microgravity where the otoliths reference is missing. The possible interaction between time and space in these fields of activity should be further explored.

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74 R Development Core Team (2006). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

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ABSTRACTS

Previous studies (Israël, Chapuis, Glasauer, Charade, & Berthoz, 1993 ; Israël, Capelli, Sablé, Laurent, Lecoq, & Bredin, 2004) showed that time was used in the estimation of a traveled distance in darkness and that the distance was overestimated. Is time estimation modified during self-motion? Blindfolded participants performed a temporal interval production task of one second while passively displaced linearly or angularly with constant or varying velocity, or immobile. The intervals regularity was impaired during self-motion compared to immobility. Furthermore the intervals rate was slowed during motion deceleration and increased during acceleration. This effect is mainly attributed to the vestibular (and somatosensory) system.

Des études précédentes (Israël, Chapuis, Glasauer, Charade, & Berthoz, 1993 ; Israël, Capelli, Sablé, Laurent, Lecoq, & Bredin, 2004) ont montré que le temps était utilisé lors de l'estimation de distances parcourues dans l'obscurité et que la distance était surestimée. La perception du temps est-elle modifiée lors de mouvement propre stimulant le système vestibulaire ?

Des participants les yeux bandés ont réalisé une tâche de production d'intervalles temporels de une seconde tandis qu'ils étaient passivement déplacés linéairement ou angulairement avec vitesse constante, variable, ou immobiles. Les résultats ont montré que la régularité des intervalles était altérée lors du mouvement propre comparé à l'immobilité. De plus, la production d'intervalles ralentissait pendant la décélération du mouvement et augmentait pendant l'accélération. Cet effet a été principalement attribué au système vestibulaire (et somatosensoriel).

INDEX

Keywords: Time Perception, self-motion, vestibular system

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